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Determining the Applicability of 3D Concrete Construction (Contour Crafting) of Low Income Houses in Select Countries

Abstract

In addition to showcasing the significance of 3D concrete printing technology, this report seeks to analyze what factors would inhibit, allow for, or facilitate Contour Crafting's success in select countries. Saudi Arabia and China would be the optimal countries to introduce Contour Crafting based on our Excel-based model that controls for variables related to wealth, size, likelihood to consume, and concrete consumption per capita. Further research on country-specific regulation fosters the hypothesis that Contour Crafting is more likely to succeed in Saudi Arabia than in China. Contour Crafting's global investing strategy will likely be through a joint venture partnership with governments via sovereign funds. Since capital partnerships seek to utilize the technology to supply low-income housing units, end users would not be able to afford the technology and would theoretically be funded by nations seeking solutions to underlying social issues impacting citizens. Overall feasibility is contingent upon government regulated housing, infrastructure, and cheaper alternatives of construction that provide adequate enclosure systems. Though Contour Crafting is a novel construction technique, it's unlikely to be adopted as an economically feasible method for affordable housing construction.

Keywords

Cornell, real estate, concrete, 3D concrete, contour crafting, build homes, saudi arabia, china, housing units, affordable, low income, affordable housing, 3D print, 3D printing, contour, crafting, development, housing, technology, urbanization

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By: David Weinstein and Peter Nawara

Executive Summary

In addition to showcasing the significance of 3D concrete printing technology, this report seeks to analyze what factors would inhibit, allow for, or facilitate Contour Crafting's success in select countries. Saudi Arabia and China would be the optimal countries to introduce Contour Crafting based on our Excel-based model that controls for variables related to wealth, size, likelihood to consume, and concrete consumption per capita. Further research on country-specific regulation fosters the hypothesis that Contour Crafting is more likely to succeed in Saudi Arabia than in China. Contour Crafting's global investing strategy will likely be through a joint venture partnership with governments via sovereign funds. Since capital partnerships seek to utilize the technology to supply low-income housing units, end users would not be able to afford the technology and would theoretically be funded by nations seeking solutions to underlying social issues impacting citizens. Overall feasibility is contingent upon government regulated housing, infrastructure, and cheaper alternatives of construction that provide adequate enclosure systems. Though Contour Crafting is a novel construction technique, it's unlikely to be adopted as an economically feasible method for affordable housing construction.

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Introduction

Contour Crafting, a pioneering process in 3D concrete construction, has the potential to change the way houses are conventionally constructed. Though the technology itself may have the capability to introduce significant automation to the construction industry, in practice, its pervasiveness is limited to its adoption. Like most new cutting-edge technologies, we expect that its use will first be novel in this case, limited to developing interesting contours for luxury homes, for use on Mars, or for when traditional labor can not accomplish what 3D concrete printing can. It's our goal in this paper to not only showcase the significance of Contour Crafting but also the applicability of the technology by determining optimal markets where it would be in-demand to provide affordable housing.

Quantitative analysis using an Excel-based model was the starting point to "weed out" countries that – objectively – would be inadequate markets to introduce Contour Crafting at this time. The countries remaining are those, that in the most basic sense, are suitable to consider implementing this automated technique as a construction method for affordable housing. Further research was collected through retrieval of secondary data – opinions, journal articles etc. – and interviews with industry professionals. This research led to identifying further variables of interest, which when cross referenced against those yielded by the quantitative analysis, fosters selected target markets to research further. The applicability study is unique in its two-fold approach, first targeting the primary consumers (sovereign funds, private firms) and then the end consumers (the individual inhabitants of the house).

Behrohk Khosnevis¹, USC Professor of Engineering and active researcher in robotics, and mechatronics related research and development projects, is accredited for developing the additive manufacturing process that he coined Contour Crafting. Khosnevis found a way to reconcile housing-construction and 3D printing technology: “Contour Crafting technology scales up automated additive fabrication from building small industrial parts to constructing buildings.”² While the Contour Crafting technique is a form of “green construction” and would be ideal for developing tricky contours that many luxury homes incorporate, for the purpose of this report, Contour Crafting is being used for development of affordable houses.

After giving a brief overview of the Contour Crafting technology and the competitive landscape, the following sections seek to:

1. identify target markets that have resources capable of mass 3D printing construction and proven demand based on affordable housing fundamentals.
2. evaluate primary research data (qualitative factors) to identify countries most likely to benefit from social impact investing.
3. expose deal structuring and partnership options that will facilitate the implementation of Contour Crafting technologies.
4. highlight a case study demonstrating macro-demand criteria that justify entering China or Saudi Arabia.

The paper will conclude by describing why Contour Crafting is unlikely to succeed as a construction method for affordable housing development.

Overview of Contour Crafting - The Technology

Significance

Contour Crafting challenges the way houses are conventionally built. As an automated construction process of whole structures, Contour Crafting seeks to increase safety standards (both for occupants and laborers) and construction efficiency at a time when: “Labor efficiency is alarmingly low, accident rates at construction sites are high, work quality is low, and a skilled workforce is vanishing.”³

As the population in developing countries grows rapidly, traditional methods of construction will not meet housing demands, especially in areas where a higher construction standard is required for safety precautions. Contour Crafting seeks to address housing problems and provide people in all countries and all societies with affordable and dignified housing.

Unique Selling Point and Proprietary Technologies

Contour Crafting (CC) is an additive fabrication technology that uses 3D printing technology and applies it to the automated output of concrete to build homes. Waste is extremely minimal because the manufacturing transforms raw materials to final product all on-site. The process starts with a 3D model based off of a “tool path.” Through computer

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1 Khosnevis is a professor of Industrial & Systems Engineering, Aerospace & Mechanical Engineering, Astronautics Engineering, Biomedical Engineering and Civil & Environmental Engineering and is the Director of the Center for Rapid Automated Fabrication Technologies (CRAFT) and Director of Manufacturing Engineering Graduate Program at USC.

2 Kawade, Amol B, Satpute, Chatali. Amrutvahini College of Engineering, Sangamner. Automated Construction By Contour Crafting. Engineeringcivil.com

3 B. Khosnevis, George Bekey, Automated Construction using Contour Crafting – Applications on Earth and Beyond

animation, any contour or free-form surface can be built ranging from traditional ‘boxy’ styles to more modern curved designs. The tool path describes the position, orientation, velocity, and deposition rate of the nozzle in the entire construction period. This information is converted into a sequence of machine tasks and then fed to the Contour Crafting machine.

As shown in Figure 1, a gantry system carrying extrusion nozzle(s) moves on two parallel tracks installed at the construction site. Trowels smooth the surface of the layers as the concrete is extruded. The cement does not require forms; each layer extruded can keep its form as each successive layer is added. Automated reinforcement is possible through the addition of steel mesh or fibers like reinforced plastics. A single house or many houses, each with possibly a different design, may be automatically constructed in a single run.

This method allows for a custom built Concrete Masonry Unit (CMU) based wall that has all utility conduits embedded in the design. The cost of construction is related to time and energy expended by the machine and the amount of materials consumed for the structure.

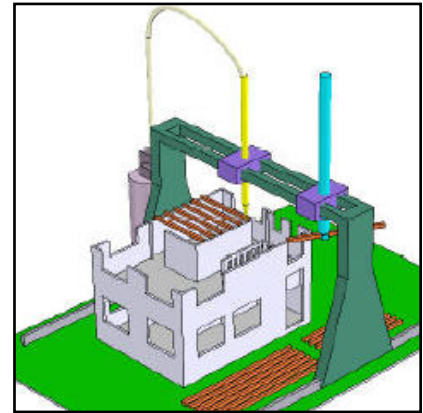


Figure 1

Contour Crafting Gantry
Crane System⁴

- Machinery needed: Gantry crane system, a nozzle assembly with three motion control components (extrusion, rotation, and trowel deflection) and a six-axis coordinated motion control system.
- Predicted result: A 2,000 square foot house can be constructed in less than 24 hours.

General Competitors (not country specific)

Currently, “Contour Crafting (CC) is one of few layer fabrication technologies that is uniquely applicable to the construction of large structures such as houses⁵” From a construction perspective, its competitors can be grouped into two categories: (1) those that are in the 3D concrete printing space and (2) those that use different means of production but advance the same mission, like prefabricated housing. Its competitors extend to any fabrication process that represents a more economical alternative and provides an adequate enclosure system for those in that region.

Competitors in 3D Concrete Printing Space

Contour Crafting is simply one method – one of the first and most established – to come into the market. Other companies in the sector include:

DUS Architects (based in Amsterdam, Netherlands) – Dubbing 3D printing technology “a new craftsmanship,” DUS Architects is a high-end focused firm that plans a one-of-a-kind 3D printed houses that architecturally stand out. The 3D Canal House is their most recent project and uses some of the most “green” materials and technology including bioplastics and glue made of 80% vegetable oil.

Yingchuang New Materials (based in Suzhou, China) – The company uses a modified version of the printers originally proliferated by Contour Crafting. WinSun Decoration Design Engineering supplies the printers that measure 20 feet in height, 33 feet in width, and span 132 feet long. According to Khosnevis, they have copied his approach, but also produce numerous false claims like: “ten buildings [can be] built in one day, while in

⁴ <http://www.craft-usc.com/wp-content/uploads/2013/10/CC.jpg>

⁵ <http://contourcrafting.org/wp-content/uploads/2013/04/AIC2004-Paper1.pdf>

reality every one of those buildings has taken [the company] a few days to build because [they're built] in several pieces in the factory with that huge non-mobile machine (a CNC machine)⁶." Prior to fabrication, each structure is meticulously planned out using a Computer Aided Design (CAD) design format as the template, then a computer controls the mechanical extruder arm to lay down specially treated concrete to 'print the structure' in a patterned layering process that simultaneously increases the strength of the structure. Unlike both DUS Architects' and Contour Crafting's 3D printing equipment, Yingchuang's technology extrudes recycled construction materials, such as sand, concrete, and glass fiber. Ten one-room structures can be built in under 24 hours. Built from predominantly recycled materials, these homes cost as little as \$4,800 USD.

Pinwheel house design – A potential competitor could be the affordable housing project called the 1K House⁷, designed by Ying chee Chui (MARCH '11), a graduate of MIT's Department of Architecture. The "Pinwheel House" consists of a modular layout with hollow brick walls, steel bars for reinforcement, wooden box beams, a central courtyard space and it is also built to withstand a magnitude 8.0 earthquake. The goal was to build the house at \$1,000, but currently, the cost to build is \$5,929. The house is structurally very sound, and could be used in areas that are often threatened by natural disasters (capable of withstanding an 8.0 magnitude earthquake). The prototype house has been constructed in Mianyang, in Sichuan Province, China. As it is in its prototype stage, further information about the project is limited.

Modeling the Feasibility for Contour Crafting to be Adopted in Select Countries

Quantitative analysis was the first step in narrowing target markets of interest. To lend insight into product attractiveness in developing and developed countries, secondary data was collected from various sources and organized according to four key variables: wealth, size, likelihood to consume, and accessibility of the resources critical to the product. Each variable was assigned a specified weight from one to five; a higher weight means that a variable has a relatively greater influence in determining product likelihood to succeed. To account for discrepancies and to be able to compare data among all four variables, data was normalized. For each country, the normalized data for each variable with applied weight was then summed. The greater the tallied score, the more likely the country exhibits demand characteristics for Contour Crafting.

Method & Variable Selection

The following variables were identified to determine which country exhibits demand characteristics for Contour Crafting:

- **Variable 1 – Wealth:** GDP at Purchasing Power Parity per Capita
 - Weighted at 1 (lowest weight) – By using data that standardizes monetary values across all nations, GDP purchasing power parity per capita determines how much a citizen contributes to its GDP. This variable identifies populations that would typically have a high demand for low-income housing. Due to massive fluctuations in population sizes, "Wealth of Nation" as measured by GDP alone is less relevant than the selected variable.

⁶ <http://3dprint.com/53437/contour-crafting-dr-khoshnevis/>

⁷ <http://newsoffice.mit.edu/2011/1k-house-prototype-0915>

- **Variable 2 – Size:** Number of Housing Units Existing in 2012
 - Weighted at 3 – This indicates the maturity of the housing market and the number of households relative to the population size. It is used to project our likelihood to consume based on population forecasts that estimate future housing unit needs.
- **Variable 3 – Likelihood to Consume:** Forecasted Single-Person Housing Need in Housing Units for 2017
 - Weighted at 5 (highest weight) – This indicates a lack of current (housing) inventory that will need to be filled by creating housing units to meet the demand of future population growth. The number of single-person households by country in 2012 was contrasted with future forecasted demand in 2017. The spread between the two signifies future demand for housing units and takes into consideration whether the selected populations are growing or retracting.
 - Note for Excel-model users: Standardized value is applied inversely because the negative number represents a lack of future housing inventory, which is in reality a demand driver (so the more negative the number, the greater the need for future housing, the more housing is currently “lacking”). Countries such as Japan and Germany are not applied inversely because they are experiencing negative population growth; only countries experiencing positive growths are applied inversely.
- **Complementary Variable – Concrete Consumption per Capita**
 - Weighted at 4 – The feasibility of Contour Crafting is dependent on the construction method’s access to concrete. If a country does not have sufficient inventory of concrete or channels of distribution to obtain it at an affordable cost, then Contour Crafting would not be used. Similarly, if there were high import costs of concrete to the project site, then Contour Crafting may not be feasible. In selecting countries used for analysis, only those that also met a standard for “concrete consumption per capita ” were determined to be viable markets for using Contour Crafting.

Data for each variable was normalized, allowing for comparison among all variables. A positive number indicates a demand for the variable while a negative one indicates that contour crafting may not work in that country because the variable in question is not satisfied. When the normalized data from each variable was summed for each country, it was then ranked according to its score (higher the rank, the higher the likelihood that Contour Crafting would be successful in that country).

Quantitative Results: Saudi Arabia and China would be the Optimal Markets for Contour Crafting (for Affordable Housing Construction)

The model takes into consideration both the primary and end-users, though only the sovereign and private companies are our initial 'targets', as they are the capital / political sources that would drive initial adoption of the product. Though ten countries were selected as markets for being the most likely to utilize Contour Crafting, only two countries were identified as optimal markets to explore further. As the Excel model reveals (refer Appendix A), some countries, such as Iran, have been removed due to insurmountable political barriers. Additionally, countries, such as Italy, have also been removed due to ongoing volatility in their capital markets. Such political and capital barriers are further

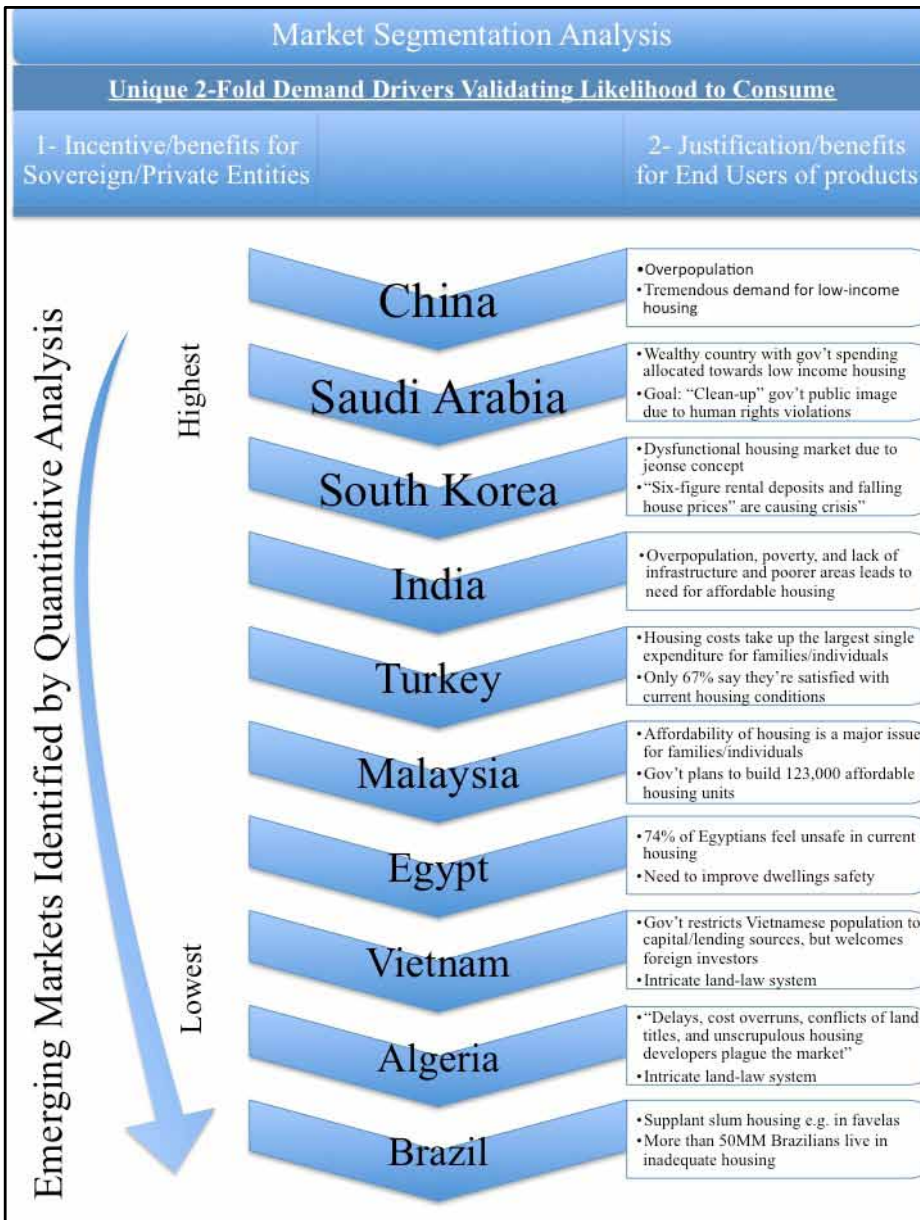


Figure 2

Market Segmentation according to the top 10 Countries most applicable for Contour Crafting

examined to the extent of the role they play in determining Contour Crafting's ability to penetrate the market effectively.

Figure 2 depicts the results of our quantitative analysis i.e. the top ten countries with the highest propensity to use the product. Please also refer to Appendix A for the quantitative analysis that justifies and corroborates our conclusions.

Primary Data Analysis: Contour Crafting is Unlikely to be Adopted as an Affordable Housing Method of Construction

In supplement quantitative analysis, primary data was collected to further identify forms of Contour Crafting's applicability in particular countries. A series of interviews were conducted to gain insight about affordable housing in developing countries, alternative methods of construction for low-income housing and 3D printing of materials. These responses helped refine market entry strategies. Among all data collected from the interviews, the key points are summarized in the paragraphs below.

For low cost/affordable housing, Contour Crafting is most applicable to wealthy countries with great wealth disparity in which the government could intervene and

subsidize housing. Demand for Contour Crafting will be accelerated by countries that experience dangers in their traditional forms of housing construction and a lack of current housing inventory. Joint ventures with sovereign funds or private corporations will be the financing approach for Contour Crafting's entry strategy.

Ultimately, the choice of enclosure systems will depend on: climate, available material types (e.g. clay, concrete), existence of infrastructure for community development (sewage, power, clean water, etc.), and transportation routes to bring materials to/from site.

Below are the key points with respect to each respondent:

- *Warren Bailey, Professor of Finance at the Samuel Curtis Johnson Graduate School of Management at Cornell University*
 - He was skeptical of using this method in developing countries because in such instances the 3D construction method would be "replacing local workers and local materials with high-tech dangerous materials." Bailey thought that a development bank partnership could be the optimal deal structure.
- *Hod Lipson, Associate Prof. of Mechanical & Aerospace Engineering and Computing & Information Science*
 - If low-cost labor is available, this method should not be pursued in developing countries.
- *Ted London, Patrimonio Hoy, Director of the Base of the Pyramid Initiative at the William Davidson Institute at the University of Michigan*
 - Mr. London noted that conventional housing methods are the greatest competitor to Patrimonio Hoy; he did not view 3D concrete printing as a threat in low-income housing communities in developing countries.
- *Heather Esper, Patrimonio Hoy, Program Manager of Impact Assessment of the William Davidson Institute at the University of Michigan*
 - Patrimonio Hoy's initiative is marketed by having "promoters." Patrimonio Hoy hires promoters from the community, so they can increase outreach and gain customers. According to Ms. Esper, they had significant challenges with the promoter model because there was a high volume of turnover.
 - The client funds the project using a 70-week saving program, and slowly, materials are bought from a construction source. The customer buys raw materials and works with local masons, per the Patrimonio Hoy-affiliated architect's design. The end user gets to help design how the house will look – they get say in it, so it is much more dignified.
 - Ms. Esper expressed the need to have a partner, in a similar way that Patrimonio Hoy is connected to Cemex.
- *Jonathan Oschorn, Professor, Director of Graduate Studies at Cornell University's College of Architecture, Art, and Planning*
 - 3D concrete printing is better suited for customization where specific designs/contours are required. 3D printing, in general, is better suited for fabrication of things like prosthetics; not concrete building since concrete housing can be fabricated using many different methods.
 - The infrastructure – planning for waste, water, etc. – is the key concern in developing large affordable housing communities. Choosing the construction method for building houses is secondary, once these systems are in place.

- The adoption of contour crafting is first and foremost a political and economic issue. If the “economics” make sense, then it comes down to choosing the material of construction that is best suited for the climate (e.g. wood would be best suited for the U.S. since it is cheaper. And, concrete is somewhat ineffective as an insulator in cold climates).
- Fundamentally, the choice of enclosure system is based on: climate, material type (e.g. clay, concrete), infrastructure for community (for sewage, water etc.), and transport routes to bring materials to/from site.

Global Entry Strategies

Contour Crafting’s global penetration strategy will likely be facilitated through a joint venture partnership with governments via sovereign funds. Private companies would potentially be attracted to Contour Crafting to enter into emergent markets that have either (1) been showing to be a proven success or (2) demonstrate a strong need for affordable housing built to the standards of 3D concrete construction. Note that there is little – if any – precedent for sale of this construction technique, so all pricing will solely be based on profitability hurdles; meaning that materials costs, labor considerations, and the scale of the projects (quantity of units produced) will likely play the biggest role in determining pricing.

JV & Management Contract Strategies Applicable to Contour Crafting

Given that Contour Crafting is in its early stages, there will likely be a demand for licensing of the proprietary technology. However, for the purpose of this paper, the main strategy considered is JV partnerships. Based on this partnership structure, Figure 3 below identifies key drivers of success for market entry strategies.

Key Drivers of Entry Strategy	JV & Management Contract Strategies
Capital Cost	Projects would be funded entirely by government budgets or sovereign wealth funds. The goal is to seek maximum equity participation of sovereign nations or private entities – to increase “skin in the game” – in order to incentivize successful completion of projects.
Human Resource Needs	As emerging markets, each country will have low-cost laborers for auxiliary and support purposes. However, some skilled labor will be required; workers will need to be trained by Contour Crafting to operate the machinery. These workers could potentially be employees of the Contour Crafting firm, and work aboard on the given projects to train other members of the construction staff.
Control of Technology	The technology will be entirely proprietary. Reproduction of it would cause Contour Crafting to lose its competitive advantage. Licensing is something that will need to be considered.

Figure 3

JV/Management Contract
Strategies Based on the Key
Drivers of Successful Market Entry

Speed to Market	This hinges on the JV partners' action plan to identify the need and pace to implement Contour Crafting. <i>Note:</i> Based on our analysis, the selected countries already have a need to (1) supply additional low income housing units and (2) can afford to execute (have the monetary capacity and material resources).
Market Learning (Adaptation/Expansion)	Because this is a new and proprietary method of construction, there will be a steep learning curve and barriers to adoption of the method. Strategically, the goal is to sell the product to the primary users (the sovereign funds etc.) and to demonstrate a need for the technology, while keeping in mind the demand from end-users of the product.
Strategic Control	It's anticipated that full strategic control will be given to the sovereign nations as they design/ master-plan the low-income housing communities via Contour Crafting construction. In order to uphold the warrantee, a member of the Contour Crafting team (or perhaps someone who is certified to use the equipment) will be on-site in the beginning stages.
Asset Exposure	As of now, there is no "template" deal structure with JV partners, so capital structure will have to be determined on a case-by-case basis.
Political Risk Management Capability	We refuse to partner in countries where political risk, corruption, and instability are likely to arise/ exist and threaten the implementation of the Contour Crafting construction method.
Quality Control	Warranties will be provided to the primary users to increase the attractiveness of the technology – the adoption rate - and provide an advantage over competitors such as pre-fabricated housing, etc. The warranty would be structured in a way that ensures that all housing units are built to a certain, promised level of quality. This would be contingent upon the users promise to utilize the recommended grade of concrete. Select parts could also be warranted, specifically those that are particularly durable e.g. the steel frame and the supports/arms on each side of the track (the wheels or mechanisms that attach to the track would not be warranted, because they're exposed to more wear-and-tear issues). The reliability of the material and the product will also give consumers confidence based on the extensive R&D that went into product development.
Income	Increased emphasis is placed on the degree of equity participation by sovereign funds, rather than the income strength of the end-consumer. The role of government subsidies will largely determine the feasibility of the product.

Entry Strategy by Selected Country

Quantitative analysis dictates that China and Saudi Arabia would be ideal countries for market entry and will be the subject of further investigation for how Contour Crafting can be implemented internationally. Ultimately, as to be discussed, we find that Saudi Arabia would be an ideal market for entry, while Contour Crafting may not be suited for the Chinese market. These sample countries demonstrate the capital and political characteristics as well as social demand drivers that would determine the feasibility of success of our international marketing plans.

Entry Strategy: China

Though China represents an ideal market for Contour Crafting – based on our quantitative research and anticipated demand from the end-users – political risks and regulation pose too much of a threat.

The End-Users

Contour Crafting's success in China hinges on the country's government housing subsidies. The end users targeted are those who would typically seek one of the following types of affordable housing options offered by the government:

- **“Cheap rental housing (CRH) -** These are rental-housing subsidies to provide provisions for rent control rent subsidies (monetary subsidies), and rent reduction to households who already live in public rental housing. These are provided by municipal government, developers, or work units and are subsidized by housing provisions with controlled rents, rent subsidies, and rent reduction. The target customers are those requiring low-income housing or have housing difficulty.
- **Economic and comfortable housing (ECH) -** Refers to ownership-oriented housing provided by developers on free land allocated by local municipalities, and sold to qualified households at government-controlled prices. These are provided by developers and subsidized by the municipal government. The target customers are low and middle-income households.
- **Public Rental Housing (PRH) -** Rental housing provided by the municipal government, work units or developers. The land can be free and rents are regulated. This targets lower-middle income households, new employees, and qualified migrants with difficult housing.⁸”

The government has been constantly adjusting its low-income housing policies to try to get all citizens to qualify for a type of affordable housing should they need it. However, a significant portion of the population are still considered “sandwich households,” those that cannot afford to purchase ECH but do not qualify for CRH. 3D concrete printing affordable houses would be fit for the sandwich households, those on the margin, but this would mean that the government would have to expand their subsidizing program.

Secondly, for those who were displaced from their houses, Contour Crafting can be used to build replacement homes efficiently. To better define the customer segment of development-induced displacement, it is important to note some of the process' causes.

- Urban infrastructure
- Water supply (Dams, reservoirs, irrigation)
- Transportation

8 Huang, Youqin. Dec. 2012. Low-income Housing in Chinese Cities: Policies and Practices. The China Quarterly, Vol. 212

- Energy (power plants, mining areas etc.)
- Agricultural expansion
- Parks and forest reserves
- Population redistribution scheme

The people who are displaced by the above causes are referred to as being part of the “costs” of displacement. The irony is that in the process of facilitating infrastructure development projects, things that are supposed to be beneficial to society, the government actually subjects the “displaced” to long-term “risks of becoming poorer than before displacement, more vulnerable economically, and can lose their livelihoods altogether.”⁹

These customers, rather than those displaced by natural disasters, human-made disasters etc., are the targeted end-users for this project, because it would be much more feasible to fund this housing project in a “high development” situation rather than one of natural disaster¹⁰ recovery. Infrastructure related projects generate substantial revenue for the government, which partly subsidizes these houses. In a disaster situation, temporary houses – that are usually sub par in status – cannot be a source of profit; also, the public generally does not criticize the government when there is a disaster of some sort and they provide shelter (since the government is the last – and often – the only resort). The targeted market experiences great variation in terms of its demographic composition, but its socioeconomic status is consistent.

Category Demand for Affordable Housing Units

In China, the government has displaced millions of people through the process of urbanization e.g. via the construction of the Three Gorges Dam¹¹ that has led to 1.4 million people displaced by the rising of the Yangtze River ‘s waters. The government exercises forced dislocation in these rural areas in the moving of households to other “cookie-cutter” like houses. Alternatively, much of the displacement involves putting people in tall buildings within affordable housing complexes. However, in the case of the Three Gorges Dam displacement, people were resettled in 20 counties around the region and typically in houses, rather than large apartment buildings¹².

Furthermore, in the future, it is foreseeable that demand for low-income housing will continue. According to Jiang Weixin, Minister of Housing and Urban-Rural Development, “The country plans to start construction of more than 6 million affordable housing units and complete the construction of 4.8 million units [in 2014]¹³. The country built 4.7 million affordable housing and started construction of 6.3 million units in 2013, according to the ministry’s statistic.” JV partnerships via public development companies will be the major builders of this project.

We know this trend will continue because the Chinese government is literally trying to change the nature of the economic system – no quick task – so that the economy is less based on exports and more on domestic consumer demand for products. Bulldozers are razing villages: “The ultimate goal of the government’s modernization plan is to fully integrate 70 percent of the country’s population, or roughly 900 million people, into city living by 2025¹⁴.” The Chinese government wants to build 36 million units of affordable housing between 2011-2015.

9 W. Courtland Robinson. May 2003. Risks and Rights: The Causes, Consequences, and Challenges of Development-Induced Displacement. The Brookings Institution-SAIS Project on Internal Displacement

10 To clarify disaster induced displacement could be from sudden impact disasters, slow-onset disasters, epidemic diseases, industrial/technological, disasters, and complex emergencies. Furthermore, refugees – as another type of displaced person – would not be able to afford a house of this sort.

11 http://www.nytimes.com/2011/05/20/world/asia/20gorges.html?_r=0

12 http://www.chinadaily.com.cn/china/2011-03/21/content_12199263.htm

13 http://www.china.org.cn/china/Off_the_Wire/2013-12/24/content_30990577.htm

14 <http://www.theatlanticcities.com/housing/2012/08/chinas-affordable-housing-going-those-who-need-it/2909/>

On a macro scale, “the government has started construction on 6.66 million affordable housing units and completed building 5.44 million in the first 11 months of 2013¹⁵, meeting its annual targets ahead of schedule, according to the country’s housing authorities on Monday.” The government is working quickly to build. And since construction stimulates the economy through not only the increase in raw materials demand but also through increasing employment, there would need to be justification for the use of 3D concrete printing – a technique that employs fewer people than conventional methods.

Purchasing Habits

Purchasing habits among the Chinese for affordable housing is utilized on a needs basis for those displaced. Displaced people tend not to have much choice about where to live, upon being evicted from their homes. A purchase by the end user tends to be made near or onsite. For the product itself though, purchase habits are non-existent. The developers, the primary users, bid on projects to build on land-leased sites (those owned by the state)¹⁶. “There are two main types of auction: regular English auction and an unusual type which we call a two-stage auction. The latter type of auction seems more subject to corruption, and to side deals between potential bidders and the auctioneer¹⁷.”

The machinery required for 3D concrete printing would have to be shipped from the U.S., where it is constructed, and assembled in China (onsite). The end users will assume the housing the same way that all other affordable housing is assumed in China, via an application process.

China-Specific Strategy for JV Partnerships

“Construction of low-income housing has been the key project vigorously promoted by the central government.¹⁸” China Development Bank would be an appropriate and particularly useful JV partner for the construction of affordable housing by means of Contour Crafting. “According to relevant personnel of China Development Bank, in Hadawan Model, China Development Bank has referred to generally accepted international practice of ‘joint-venture by the public and private enterprises’ to establish company for special purpose with joint investment from social capitals responsible for financing, developing, organizing and constructing specific areas of the city based on implementation of relevant documents of the State Council on standardization of liability of local government and rectification of original local financing platform.”

Furthermore, the China Development Bank has led all financing strategies for shantytown reconstruction. Additionally, “according to relevant personnel from China Development Bank, since 2005, to solve the capital restrictions on shantytown reconstruction projects, China Development Bank has used market construction methods to jointly establish market financing platform with local government to integrate various resources.” Since they already have this platform in place where they use market construction methods, it might be fairly difficult to have them adopt Contour Crafting and JV.

Competitors

The large-scale development of housing funded by the government remains to be a competitor. Developers subsidized by the government for affordable housing – more

15 http://news.xinhuanet.com/english/china/2013-12/16/c_132971549.htm

16 China’s Land Market Auctions: Evidence of Corruption. Hongbin Cai, J. Vernon Henderson, Qinghua Zhang. NBER Working Paper No. 15067. Issued in June 2009. Retrieved from: <http://www.nber.org/papers/w15067>

17 <http://www.nytimes.com/2013/06/16/world/asia/chinas-great-uprooting-moving-250-million-into-cities.html?pagewanted=all>

18 <http://www.cdb.com.cn/english/NewsInfo.asp?NewsId=4723>

broadly – represent competitors (primary users, those who utilize the machinery). In its current format, workers and funding bodies associated with these large-scale affordable housing projects are incentivized by:

- a guarantee of a 3% profit margin.
- little money down (as little as 20% of their equity).
- increased chance of winning public land at auction after helping to develop an affordable housing project (product of government control in land production).

Additionally, with the government becoming less involved in business and moving towards a globalized “western-world” laissez-faire platform, this increases our risk of foreign competitors entering the market.

Risks of Market Entry Threaten Success

Despite the potential success of high demand and JV partnerships, a changing market and political risk threaten the success of the product. While the quantitative model used indicates that China is the best fit for the product being sold, it does not take into account viability of the market – the threat of potential competitors – or government regulation. As a result, despite the variables used lending insight into country selection for the product, such is not sufficient to decide whether the country would be a favorable choice for the product.

For specifically the affordable housing market, an enormous risk is related to the lack of reliable information in China that makes it difficult to determine who is entitled to low-income housing. Since the penalty for false application is negligible (the customer merely has to give back the unit and move out), potential customers are increasingly forging.

Government confiscation of houses is undoubtedly a potential risk to the end users, who do acquire their houses in a legal way by presenting truthful applications. With the government owning 30% of the equity in all the ECH homes, there is an element of government control involved in all the houses.

Corruption of the housing market makes it particularly risky to enter. “China’s affordable housing program lost nearly 6 billion yuan to embezzlement last year; the national auditor reported on Friday, underscoring the obstacles to official efforts to fight graft.¹⁹” Additionally, “In 2012, the government invested 412.9 billion yuan in affordable housing, while another 466.8 billion yuan came from bank loans, bonds, and other social financing, according to the report. The real amount of money that was lost may be higher than reported, Jinsong Du, a Hong Kong-based property analyst at Credit Suisse Group AG, said in a phone interview.²⁰”

The two-stage auction model, as described above, is corruptible and presents a threat. Government officials can alter the selection technique as a way to pass along better properties to groups of their preference.

Entry Strategy: Saudi Arabia

To understand Saudi Arabia’s motivation to a more progressive and humanitarian-abiding position in the global sphere, we need to take a look at the drivers of this change. As Saudi Arabia has joined NATO and the U.N., it is actively seeking to make progress to conform to the values and practices mandated by the respective organizations. As Saudi Arabia has joined NATO and the U.N., it is actively seeking to make progress to conform

¹⁹ <http://www.scmp.com/news/china/article/1295517/nearly-6b-yuan-stolen-china-low-cost-housing-programme>

²⁰ <http://www.bloomberg.com/news/2013-08-09/china-finds-abuses-nearing-1-billion-in-affordable-housing-push.html>

to the values and practices mandated by the respective organizations. Contour Crafting – through producing large scale and safe, affordable housing – can effectively penetrate the market by addressing massive gaps in housing affecting migrant worker populations.

Preface: A Brief Overview of Saudi Arabia's Recent Human Rights Violations

Though a member of the United Nations, Saudi Arabia is notorious for historically behaving negligently towards several documented cases of human rights abuse. It has been argued that several nations disregard this because The Kingdom maintains a notable presence internationally as the world's second largest oil producer and largest exporter. King Abdullah bin Abdul Aziz, having defended Saudi Arabia's position on human rights in 2000, stated that "it is absurd to impose on an individual or a society rights that are alien to its beliefs or principles"²¹. The violations range from still culturally acceptable public executions by beheading, severe oppression of the female population, and for the context of this assignment- treatment of illegally registered migrant workers. The following excerpts from the CIA World Factbook lend insight into Saudi Arabia's current geopolitical issues.

"King Abdallah since 2005 has worked to incrementally modernize the Kingdom - driven by personal ideology and political pragmatism - through a series of social and economic initiatives, including expanding employment and social opportunities for women, attracting foreign investment, increasing the role of the private sector in the economy, and discouraging businesses from hiring foreign workers. The Arab Spring-inspired protests - increasing in number since 2011 but usually small in size - over primarily domestic issues among Saudi Arabia's majority Sunni population. In addition, Saudi Arabia has seen protests among the Shia populace in the Eastern Province, who have protested primarily against the detention of political prisoners, endemic discrimination, and Bahraini and Saudi Government actions in Bahrain. Protests are met by a strong police presence, with some arrests, but not the level of bloodshed seen in protests elsewhere in the region. In response to the unrest, King Abdallah in February and March 2011 announced a series of benefits to Saudi citizens including funds to build affordable housing, salary increases for government workers, and unemployment entitlements. To promote increased political participation, the government held elections nationwide in September 2011 for half the members of 285 municipal councils - a body that holds little influence in the Saudi Government. Also in September, the king announced that women will be allowed to run for and vote in future municipal elections - first held in 2005 - and serve as full members of the Advisory Consultative Council. The country remains a leading producer of oil and natural gas and holds about 17% of the world's proven oil reserves. The government continues to pursue economic reform and diversification, particularly since Saudi Arabia's accession to the WTO in 2005, and promotes foreign investment in the kingdom. A burgeoning population, aquifer depletion, and an economy largely dependent on petroleum output and prices are ongoing governmental concerns."²²

The Opportunity and Customers Targeted

The strategy proposed to gain entry into the Saudi Arabian market is opportunistic. Historically, little effort has been made by the nation to recognize these issues, though human rights abuses are outlawed by all UN Conventions. More recently, however, the country has taken great strides in culturally progressing to a more globalized society. Saudi Arabia has committed to a "'gradual reform programme' (and) in 2013, (is) making

²¹ Prince Abdullah Bin Abdul Aziz Al Saud (6 September 2000). "Statement by Prince Abdullah Bin Abdul Aziz, King of Saudi Arabia, during the U.N. Third Millennium Summit". Retrieved 3 October 2012.

²² CIA- The World Factbook- About 'Saudi Arabia'
<https://www.cia.gov/library/publications/the-world-factbook/geos/sa.html>

incremental improvements, including on human rights, while managing societal resistance to change”²³. The country is looking to improve its image in the public eye, having even hired MSL Group Qorvis for its reputation management, government relations, and public diplomacy services.

There are existing products that house these migrants workers, but unfortunately they are criticized as the equivalent of Gulags and slave camps¹⁸. Given the availability of low-cost labor for construction in Saudi Arabia, it is counterintuitive for the government to use these transients as laborers when they are trying to reduce the frequency of human rights violations. Due to the prevailing circumstances, Contour Crafting may be the solution to the inhumane housing conditions these transients reside in.

The targeted initial consumer would be the nations’ sovereign wealth fund or another government-backed entity. The thesis would be to enter into JVs or be hired as contractors by Saudi Arabia to build new housing developments to improve the living conditions of the migrant worker population, many or most of whom are unregistered. This contingent is predominantly comprised of third world country citizens, many of whom have their passports confiscated upon arrival, and are forced to live in unacceptable housing conditions. The group is inadequately protected by existing labor laws in the country, vulnerable to sexual and physical abuse and at peak times have been estimated to even reach numbers approximately the size of 1/3rd of the nation’s own population. Though it seems irrational to expect such a partnership, there is great opportunity as the country, and its leaders are actively committed to bettering their reputations on a global stage and amending many of their past faults. As the ground for evidence to our hypothesis, “In the hope of ending a shortage of homes which has depressed living standards and is politically sensitive for the government. After social discontent prompted uprisings elsewhere in the Arab world in 2011, King Abdullah announced (in 2013) a plan to build 500,000 homes in Saudi Arabia over several years. Some \$67 billion of state funds were earmarked for the plan”²⁴.

Potential Demand & Purchasing Habits

The timing for Contour Crafting to enter the market is ideal as this is part of the ongoing transformation of the Saudi Arabian government and would generate great positive publicity. The comparative advantages offered by the technology would be immense. However, the programme has been slow to get underway because of sluggish bureaucracies, difficulties in obtaining suitable land and the complexity of allocating aid. The new scheme, named ESKAN - the Arabic word for housing - and launched by the Ministry of Housing last week, aims to break through those bottlenecks²⁵.” Contour Crafting provides the perfect synergies at the perfect time for a potential partnership opportunity. ESKAN presents itself as an ideal primary customer.

Saudi Arabia currently has a severe issue with housing supply for these types of migrant workers, there are currently an estimated 8 million registered for employment in the service industry there with visas, not accounting for those illegally employed. Many enter the country unknowingly signing contracts that commit them to ‘indentured slavery’²⁶, a significant portion of these people live in forced confinement pending on the terms in which they entered the nation.

23 Government of the United Kingdom, Foreign & Commonwealth Office, Corporate Report- ‘Saudi Arabia- Country of Concern’. <https://www.gov.uk/government/publications/saudi-arabia-country-of-concern/saudi-arabia-country-of-concern>

24 Reuters- Saudi Arabia launches new housing scheme to ease shortage- Thursday, 13th March 2014.

25 <http://www.reuters.com/article/2014/03/13/saudi-housing-idUSL6N0MA17I20140313>

26 Cooper, Nicholas. City of Gold, City of Slaves: Slavery and Indentured Servitude in Dubai. University of Mexico. Journal of Strategic Security. Fall 2013. Vol 6, No. 5.

Competitors

Contour Crafting likely will not be threatened by prefabricated housing techniques made in a factory, since the costs to distribute those materials around the country would most likely be higher than using isolated land to “roll out” housing units generated by the technology.

Saudi Arabia could be an ideal environment to apply contour crafting partly because of its accessibility to concrete and its existing human rights violations related to the labor pool. The country is already the highest consumer of concrete per capita (refer to Excel Model), and this building aggregate is highly adaptable, sustainable, and suitable to the environment.

Specific Strategy for JV Partnerships

JV Partnerships with government/sovereign entities will facilitate Contour Crafting’s market penetration and growth. Due to the nature of this country and its unique political system, Contour Crafting could theoretically lead to mass adoption.

Due to the make-up of the country’s leadership made up of Royal decree, most private development companies from the region have many intricate connections between both Government, private and public sector leadership positions. For this reason, a JV structure with the Government/Royal Family or product licensing tactic would be best suited for a deal structure.

Conclusion

The likelihood of adoption of Contour Crafting technology is based on so many factors, but primarily, relative costs of construction, high initial costs to market, and political issues.

In terms of the country-specific case studies, Saudi Arabia would be better suited than China to adopt Contour Crafting for use in affordable housing projects. It is illogical to use contour crafting in a country that has low-cost labor where houses can be built relatively cheap. However, the automated method could be used in a country that is (1) seeking to overcome a social barrier/issue where all construction is typically done “by hand” and (2) where there tends to be little specialization of labor, so housing quality is unsafe.

Overall, it is unlikely that Contour Crafting will be adopted as an affordable housing method for construction. It is more likely to be adopted first for novel uses like to build luxury homes with unique contours and for use on the moon/mars. As construction becomes less labor intensive and increasingly more automated, Contour Crafting will be at the forefront in facilitating the change in ways structures are traditionally built and constructed.

Appendix A

SUMMARY FINDINGS- Peter Nawara & David Weinstein														
Weights Applied to All Countries that Cross-List Across all Variables														
	Variable 1- Wealth (at weight of 1)			Variable 2- Size (at weight of 3)			Variable 3- Likelihood to Consume (at weight of 5)			Complementary Variable- (at weight of 4)			Rough Results	
	GDP at Purchasing Power Parity per Capita			Number of Housing Units Existing 2012 (in 000's)			Forecasted Single-Person Housing Need in Housing Units for 2017 (Future Demand Indicator)			Concrete Consumption per Capita				
Country List	Given Value	Standardized Value	Standardized Value with Applied Weight	Given Value	Standardized Value	Standardized Value with Applied Weight	Given Value	Standardized Value	Standardized Value with Applied Weight	Given Value	Standardized Value	Standardized Value with Applied Weight	Total	
Saudi Arabia	28,185	1.04861	1.04861	5,155	0.50010	1.50029	0.20278	0.18665	0.93325	1,683	2.92580	11.70319	12.185	
China	8,051	0.67301	0.67301	433,841	4.10286	12.30859	0.38870	0.10208	0.51039	1,581	2.66488	10.65954	22.806	
South Korea	32,410	1.40987	1.40987	18,632	0.35539	1.06617	1.39770	0.35690	1.78452	911	0.95104	3.80415	2.363	
Iran	12,588	0.28506	0.28506	20,972	0.33026	0.99078	0.12608	0.22154	1.10770	770	0.59036	2.36144	2.193	
Turkey	13,830	0.17886	0.17886	19,309	0.34812	1.04436	0.13570	0.21716	1.08582	744	0.52385	2.09541	1.958	
Malaysia	15,632	0.02479	0.02479	6,826	0.48215	1.44646	0.14221	0.21420	1.07101	616	0.19643	0.78573	0.385	
Vietnam	3,170	0.09039	0.09039	22,444	0.31446	0.94337	0.13309	0.21835	1.09177	560	0.05318	0.21274	0.729	
Egypt	6,351	0.81842	0.81842	17,266	0.37006	1.11018	0.14885	0.21118	1.05592	554	0.03784	0.15135	0.721	
Italy	29,739	1.18148	1.18148	24,897	0.28812	0.86436	0.94344	0.15026	0.75132	546	0.01737	0.06949	0.365	
Algeria	7,049	0.75870	0.75870	6,129	0.48964	1.46891	0.21889	0.17932	0.89661	524	0.03890	0.15561	1.487	
Morocco	4,881	0.94410	0.94410	5,665	0.49462	1.48386	0.23045	0.17406	0.87032	498	0.10541	0.42164	1.979	
Poland	19,194	0.27978	0.27978	14,801	0.39652	1.18957	8.36930	3.52819	17.64095	489	0.12843	0.51373	19.064	
Spain	29,643	1.17324	1.17324	18,120	0.36089	1.08266	0.98811	0.17058	0.85292	438	0.25889	1.03556	1.798	
Russia	16,264	0.02924	0.02924	56,230	0.04832	0.14495	3.24733	1.19827	5.99137	402	0.35098	1.40391	7.221	
Thailand	8,839	0.60564	0.60564	21,202	0.32779	0.98338	0.84731	0.10654	0.53268	367	0.44051	1.76202	3.884	
Germany	36,891	1.79307	1.79307	40,017	0.12577	0.37731	0.37346	0.44877	2.24387	342	0.50446	2.01782	2.846	
Brazil	11,199	0.40386	0.40386	57,503	0.06198	0.18595	0.29140	0.14634	0.73169	330	0.53515	2.14060	1.627	
Japan	34,534	1.59147	1.59147	51,328	0.00432	0.01296	5.67831	2.66188	14.30939	329	0.53771	2.15084	14.882	
France	34,339	1.57483	1.57483	27,709	0.25793	0.77378	1.06248	0.20441	1.02207	327	0.54283	2.17130	12.392	
Mexico	14,622	0.11118	0.11118	29,770	0.23580	0.70739	0.76601	0.06956	0.34779	300	0.61189	2.44756	3.614	
Indonesia	4,473	0.97902	0.97902	62,570	0.11639	0.34917	0.62161	0.00387	0.01936	202	0.86257	3.45029	4.099	
India	3,511	0.06125	0.06125	233,029	1.94667	5.84001	0.11955	0.22451	1.12256	191	0.89071	3.56284	2.338	
Pakistan	2,619	0.13754	0.13754	19,212	0.34916	1.04749	0.21014	0.18330	0.91652	129	0.04931	4.19722	5.466	
Nigeria	4,113	0.00979	0.00979	28,900	0.24514	0.73541	0.17511	0.19924	0.99618	108	1.10302	4.41209	5.161	

27 <http://www.contourcrafting.org/space-colonies/>

Sources of justification (by country, associated with Excel model):

South Korea: <http://www.theguardian.com/housing-network/2014/jan/20/south-korea-housing-problem-jeonse-rent>

India: <http://www.firstinitiative.org/content/index.cfm?ctID=120>

Turkey: http://www.academia.edu/319455/An_Analysis_Of_The_Opportunities_And_Weaknesses_Of_The_Turkish_Real_Estate_Market

Malaysia: <http://economicsintaylors.wordpress.com/2012/10/26/housing-issues-in-malaysia/>

Egypt: <http://www.dailynewsegypt.com/2013/09/08/egyptians-living-conditions-and-their-expectations-for-the-future-poll/>

Vietnam: <http://english.vietnamnet.vn/fms/business/90239/property-market--doors-open-to-foreigners--but-locked-to-vietnamese.html>

Algeria: <http://www.english.globalarabnetwork.com/201102038874/Real-Estate/real-estate-market-building-strong-foundations-in-algeria.html>

Brazil: <http://www.theguardian.com/housing-network/2013/jan/03/brazil-slum-housing-local-solutions>

Appendix A

10 Selected Markets to Inspect	
Country	Rank
China	1
Saudi Arabia	2
South Korea	3
India	4
Turkey	5
Malaysia	6
Egypt	7
Vietnam	8
Algeria	9
Brazil	10

Notes
Iran removed due to insurmountable political barriers
Italy removed from high barriers to entry due to developed capital markets

Notes
Japan and Germany not applied inversely because experiencing negative growth in population
Lacking some info on current Households per Capita due to outdated census info

< Estimated using regression

